Construction and Building Materials 51 (2014) 97–105

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# Properties of a lightweight cement composite with an ecological organic filler

Michał Bołtryk, Edyta Pawluczuk *

*Faculty of Civil and Environmental Engineering, Bialystok University of Technology, Wiejska 45E, Bialystok 15-351, Poland*

## HIGHLIGHTS

- Two-stage technology of organic filler mineralisation is determined.
- Appropriate consolidation method of mixture is established.
- Chemisorption abilities of cement composite and of organic filler are determined.
- Microstructure of cement composite with reed and sawdust is examined.

## ARTICLE INFO

*Article history:*
Received 3 August 2013
Received in revised form 12 October 2013
Accepted 31 October 2013
Available online 21 November 2013

*Keywords:*
Common reed
Sawdust
Lightweight cement composite
Mineralisation
$CO_2$ carbonation

## ABSTRACT

This study aimed to establish the properties of lightweight cement composites with organic fillers, such as common reed and conifer sawdust. The reed *Phragmites australis* is a notably common plant in Poland that grows on waterlogged lands, and sawdust is a waste product that appears during the mechanical processing of wood.

The first step was to determine the influence of the mineralisation on the water absorbability of the organic filler. Next, the influences of the superplasticiser (SP) content and the method of mixture consolidation on cement composite properties, such as the compressive strength, the water absorbability, the density and the porosity structure, were established. The chemisorption abilities of the cement composite and of the organic filler were also determined.



## 1. Introduction

Economic development, the increase in the environmental awareness of societies and ecological reasons require the construction industry to apply recyclable [1,2] and renewable materials within a human life period [3–6]. Due to the decreasing deposits of natural aggregates that are used as basic building materials, as well as environmental reasons, the use of waste materials, such as sawdust and shavings [7–12], and organic materials, such as hemp and straw, is becoming justified in concrete technology [13–15]. In Poland, as well as in the rest of Europe, these types of building materials are not applicable on the mass scale. The use of these materials is hampered by the habit of using ordinary cement concrete with mineral aggregates, as well as by a lack of research into the properties of cement composites with plant fillers.

For many years, authors have used tree waste and plant fillers in lightweight concrete [16–19]. In this paper, the influence of organic filler mineralisation on cement composite properties was analysed. In this research, the common reed *Phragmites australis* and conifer sawdust were used as the filler. The common reed is the most popular plant that is grown on waterlogged lands in Poland and in many other countries. This reed is a valuable plant, finding application in the building construction as a material with high thermal insulation properties. The reed has also ecological advantages. During its period of growth, the reed absorbs $CO_2$ from air and builds the gas into the structure of its tissues. The reed is also cultivated in sewage treatment plants as a recycler of chemical pollutions. The young plants are used as a feed, and the rhizomes of the reed are used in health care. The composition of reed grass is approximately 10.8% mineral compounds, mainly silica. The grass also contains sugars, wax and saponins. Reed grass has high fire and frost resistances, high pH and high salinity. Because of all these properties, the reed has been applied in building construction for many years in the form of insulating boards, under-plaster mats or roofs covering. There have been made attempts to use this reed in reed-concrete structural elements [20,21].

Frothing agents in the reed, such as wax and saponins, cause technical problems in the process of mixture consolidation and specimen formation. The authors therefore examined the selection of the mixture consolidation method.

* Corresponding author. Tel.: +48 696945904.
*E-mail address:* e.pawluczuk@pb.edu.pl (E. Pawluczuk).

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.10.065

Because a lightweight cement composite with an organic filler is a porous material, a high probability exists that the composite has chemisorption properties connected with its carbonation. A significant amount of the calcium hydroxide in the lightweight cement composite with the organic filler reacts with the atmospheric carbon dioxide and, as a result, the calcium carbonate is formed [22–24]. In addition, hydrated calcium silicate (CSH), un-hydrated tri-calcium silicate ($C_3S$) and bi-calcium silicate ($C_2S$) also consume carbon dioxide [25–29]. During the carbonation process of calcium silicate, in addition to the precipitation of the $CaCO_3$ content, a silica gel forms. This gel accumulates in pores that are larger than 100 nm, which facilitates further carbonation. This phenomenon has a great ecological significance. It is possible that cement hydration products in composites with organic fillers absorb not only carbon dioxide but also other greenhouse gases.

This study objected to establish the properties of lightweight cement composites with an organic fillers such as common reed and conifer sawdust, to identify the possibilities of the improvement of its quality and to determine the ways of using it in the building construction.

## 2. Materials and experimental methods

### 2.1. Materials

#### 2.1.1. Cement

Portland cements CEM I 32.5R and CEM I 52.5R specified in the Polish standard PN-EN 197–1 (*Cement – Part* 1: *Composition, specifications and conformity criteria for common cements*) were used. The cements' physical properties and chemical compositions are listed in Table 1.

#### 2.1.2. Organic filler

In laboratory tests, conifer sawdust and common reed were applied as the organic filler (Fig. 1).

Reed particles was cut in the winter period and, after drying, was cut into 5–20 mm long pieces. Next, the straw was sieved to obtain two different fraction of reed: 2–10 mm and 10–20 mm. The reed should not be mouldy and should not have a dark colour. Conifer sawdust was delivered from the nearby sawmill and sieved to obtain a dust size range of 0–2 mm. Both the reed and the sawdust were stored in laboratory air-dry conditions. The main physical properties, such as the bulk density, the skeletal density, the water absorption ($W_A$) and the humidity ($H$), of the organic filler are given in Table 2.

#### 2.1.3. Resin

The Ceresit CT17 resin consisted of a styrene–acrylic copolymer, additions and water. This resin is a substance for surface strengthening all water absorbability bases. The range of concentration of resin used in experiment was 0–22.5% in relation to the mass of the organic filler.

#### 2.1.4. Superplasticiser (SP)

An Addiment FM6 superplasticiser, which significantly reduced the amount of water, was applied. In our examinations, the SP improved the mixture's workability and facilitated the consolidation of the specimens at the constant contents of cement and water. In the cement composite the superplasticiser content changed from 0% to 4% in relation to the cement mass.

**Table 1**
The physical properties and chemical compositions of the cements.

| Parameter | CEM I 32.5R | CEM I 52.5R |
|---|---|---|
| *Chemical composition (%)* | | |
| $SO_3$ | 2.87 | 3.4 |
| $Cl^-$ | 0.06 | 0.03 |
| $Na_2O$ | 0.81 | 0.9 |
| Insol. | 1.28 | 0.4 |
| Ign. Loss | 1.84 | 3.1 |
| *Compressive strength (MPa)* | | |
| 2 days | 25.6 | 36.9 |
| 28 days | 49.0 | 58.0 |
| Initial setting time (min) | 165 | 179 |
| Final setting time (min) | 225 | 217 |
| Specific surface ($cm^2/g$) | 3500 | 4120 |

#### 2.1.5. Chemical agents

For the mineralisation of the reed and the sawdust, two type of chemical agents, aluminium sulphate $Al_2(SO_4)_3$ and hydrated lime $Ca(OH)_2$ (9% and 18% in proportion to the mass of the organic filler respectively) were used. These agents were selected based on the analogy of mineralisation technology for wood shavings [16–18]. Mineralisation by the $Al_2(SO_4)_3$ solution prevents the organic filler against the dissolution of compound sugars and reduces the hygroscopicity and water absorption of the filler. In its hydrated form, aluminium sulphate should have an acidic reaction (pH = 3–5). The presence of hydrated lime increases the effectiveness of the aluminium sulphate action, neutralises the acidic reaction of the agent, and improves the mixture's workability.

### 2.2. Organic filler mineralisation process

Reed and sawdust constitute essential compositions of the lightweight cement–organic composite and contain many organic compounds such as polyoses, starch, cellulose, hemicellulose, pentosans or pectins, which may decompose in acids or alkaline environments into monosaccharides – saccharose, glucose and xylose. These monosaccharides retard hydration of the cement, especially in the initial period, due to the significant diffusion resistances. Another harmful result of the adsorption layers is the loss of the ability of the cement grains to coagulate. Tricalcium silicate ($3CaO{\cdot}SiO_2$) as the main cement component increases the early compressive strength of the cement composite but is also the most susceptible to the harmful influence of carbohydrates. Therefore, carbohydrates are purposefully eliminated from the reed (especially from its surface layers) and are bound into compounds neutral to cement hydration. Mineralisation allows the organic filler to resist decay, increases durability and decreases such properties as water absorption, susceptibility to volume changes and shrinkage. Mineralisation also results in better adhesion of the filler to cement paste and decreases the composite's initial setting time and hardening [19].

At the Bialystok University of Technology, the following mineralisation process was developed [16,18]: 9% aluminium sulphate $Al_2(SO_4)_3$ and 18% hydrated lime $Ca(OH)_2$ in proportion to the mass of the organic filler are dissolved in mixing water divided into two equal parts. First, the organic filler is mixed with $Al_2(SO_4)_3$ for 3 min to a homogeneous saturation. After waiting 15 min, $Ca(OH)_2$ is added, and all components are mixed again for 1 min.

### 2.3. Preparation of specimens

To apply the mixture composition onto 1 $m^3$ of area, the two-stage covering method by Paszkowski was used [18]. The mixture compositions for each experiment are given in Tables 3 and 4. After mineralisation of the organic filler (p. 2.2.), cement was added and mixed for 3 min to obtain a homogeneous mass. The consistency of the mixture should be S2 (slump 50–90 mm). Next, the cement composite mix was cast into 10 × 10 × 10 cm moulds and compacted manually into three equal layers using a 1.8 kg metal. Every layer was compacted by 15 blows of the compactor falling freely from a height of approximately 10 cm onto the mixture surface. The specimens were demoulded after 1 day and were then placed on the wooden grid where they cured in air-dry conditions at 50–60% RH and at a temperature of 20 ± 2 °C until the specimens were 28 days old. This process allowed for regular drying of the specimens. For the $CO_2$ carbonation test (p. 3.3.) the upper surface of the specimens, after demoulding, was smoothed by a 0.5–1.0 cm layer of the cement mortar with a cement-to-sand ratio of 1:1 to imitate outside plaster.

### 2.4. Experimental methods

#### 2.4.1. Water absorption test of the organic filler

The water absorption test of the organic filler was conducted according to the standard EN 1097-6 (*Tests for mechanical and physical properties of aggregates. Determination of particle density and water absorption*). For the test reed samples fraction 2–10 mm (500 g) were used and were dried at a temperature of 70 ± 5 °C to a constant mass. After the mineralisation process, all specimens were dried again at the same temperature, weighed and then saturated with water at a temperature of 20 ± 2 °C. Because the organic filler is lighter than water, the filler was put into nets and properly ballasted. Before each weighing, water present at the surface of reed particles was removed with an absorbing cloth. A constant mass of the filler was obtained after 2 days of saturation.

#### 2.4.2. Water absorption test of the cement composite

The water absorption test of the cement composite was conducted on 10 × 10 × 10 cm cubic specimens according to the Polish standard PN-88/B-06250 (*Ordinary concrete*). The specimens were saturated with water until full saturation and were then dried to a constant mass.

#### 2.4.3. Compressive strength test

The compressive strength test was conducted on 10 × 10 × 10 cm cubic specimens in accordance with EN 12390-3 (*Testing hardened concrete – Part* 3: *Compressive strength of test specimens*).